Nontarget Arthropod Abundance in Areawide-Managed Corn Habitats Treated with Semiochemical-Based Bait Insecticide for Corn Rootworm (Coleoptera: Chrysomelidae) Control

M. A. BOETEL,[1] B. W. FULLER, L. D. CHANDLER,[2] J. J. TOLLEFSON,[3] B. L. MCMANUS, N. D. KADAKIA, P. D. EVENSON, AND T. P. MISHRA

Plant Science Department, Northern Plains Biostress Laboratory, South Dakota State University, Brookings, SD 57007

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ABSTRACT Impacts of semiochemical-based insecticidal bait applications on beneficial arthropod groups common to field corn, *Zea mays* L., habitats were assessed in areawide-managed field sites in South Dakota and Iowa during 1997 and 1998. Slam, a commercial bait formulation comprised of 87% cucurbitacin and 13% carbaryl insecticide, was used for management of adult rootworm, *Diabrotica* spp., and controls consisted of cornfield habitats without bait applications. Effects on beneficial organisms were variable, and negative impacts were infrequent. Coccinellidae, Staphylinidae, and Anthocoridae were usually more abundant in bait-treated plots than in controls that received at-plant soil insecticides, especially by 4 wk postapplication. Carabid beetle activity also had increased in bait-treated corn by proportionally greater rates than in control plots at 4 wk postapplication in two of the four site by year combinations in this study. Impacts of semiochemical-based adulticide applications on Formicidae were not consistently negative or positive. The relative lack of consistent negative impacts on nontarget arthropods suggests that other biotic and abiotic factors leading to natural population fluxes may have more influence on these groups of beneficial organisms than applications of semiochemical-based bait containing carbaryl. Overall, it seems that areawide applications of these baits for managing rootworm populations in corn are not likely to impose deleterious effects on the nontarget faunal groups we surveyed, especially in comparison with the at-plant applications of soil insecticides used as experimental controls in this study.

KEY WORDS semiochemical, areawide control, nontarget organism, beneficial arthropod, *Diabrotica* spp.

ADULTICIDES FOR CONTROLLING CORN rootworm, *Diabrotica* spp., beetles have been used to prevent silk feeding damage, oviposition, and subsequent larval infestations to corn, *Zea mays* L., in portions of the midwestern Corn Belt for decades (Pruess et al. 1974). More recently, semiochemical-based insecticidal baits with low (i.e., 2–13%) concentrations of active ingredient have been evaluated for prospective use in adult rootworm control programs (Metcalf et al. 1987, Lance 1988, Lance and Sutter 1990). Slam (Micro Flo Company, Memphis, TN) is a bait material containing cucurbitacin from powdered wild buffalo gourd, *Cucurbita foetidissima* H.B.K., and carbaryl as the insecticide active ingredient. Cucurbitacins are tetracyclic triterpenoids found in most members of the Cucurbitaceae plant family that act as potent arrestants and feeding stimulants in adult *Diabrotica* (Metcalf et al. 1982). Semiochemical baits have been tested for efficacy in large-scale (i.e., 41.4-km^2) landscapes for areawide management of corn rootworms (Faust and Chandler 1998). The cucurbitacin-based strategy for adulticiding corn rootworms was suggested by Sutter et al. (1998) as having favorable potential for allowing significant reductions in the overall insecticide load applied to corn while maintaining effective rootworm management in the central core of areawide-managed sites. Subsequently, areawide use of semiochemical-based adulticides was shown to provide effective control of western corn rootworm, *D. virgifera virgifera* LeConte, and Mexican corn rootworm, *D. v. zeae* Krysan & Smith in field trials (Chandler 2003). Areawide-managed sites involving semiochemical-based adulticides have successfully been implemented for rootworm management on large farms or through cooperative efforts on smaller farms in Kansas (Wilde 2003) and Texas (Hoffmann 2003).

Most research on semiochemical-based baits for rootworm management has focused on control, although some work has been done to assess the impacts of the baits on nontarget organisms. Ellsbury et al.

[1] Department of Entomology, North Dakota State University, 202 Hultz Hall, P.O. Box 5346, Fargo, ND 58105.

[2] USDA–ARS, Northern Plains Area Office, 2150 Centre Ave., Building D, Suite 300, Fort Collins, CO 80526-8119.

[3] Department of Entomology, Iowa State University, 17 Insectary Bldg., Ames, IA 50011.

(1996a) exposed larval green lacewings, *Chrysoperla carnea* (L.), and adult convergent lady beetles, *Hippodamia convergens* Guérin-Méneville, to field-collected corn leaves that received semiochemical-based insecticidal baits at 1, 2, 3, and 4× the labeled rate of carbaryl active ingredient. They observed no significant mortality on either predator. Additional laboratory work by Ellsbury et al. (1996b) demonstrated that survival in adults of five carabid species belonging to the *Harpalus* and *Pterostichus* genera was not affected despite direct feeding on Slam-killed *D. v. virgifera* adults. McKenzie et al. (2002b) conducted similar consumption bioassays by feeding Slam-killed *D. v. virgifera* beetles to adult *Harpalus pennsylvanicus* De Geer, and observed no negative impacts from the bait on survival of the carabid. In field experiments conducted in Kansas, McKenzie et al. (2002a) found no significant effects of Slam applications on late-season *H. convergens*, *Orius insidiosus* Say, or Araneae abundance for up to 16 d after areawide treatment of corn with Slam.

The primary objective of this experiment was to assess the impacts of areawide applications of semiochemical-based baits containing carbaryl for adult corn rootworm management on nontarget arthropod groups common to South Dakota and Iowa corn field habitats.

Materials and Methods

This study was a subcomponent of the national Areawide Pest Management of Corn Rootworm in Maize Production Systems project, a collaborative research initiative aimed at investigating several aspects of areawide rootworm management in major corn production areas of the United States. Locations for the experiment were established in grower-planted cornfields within areawide rootworm management research sites in Clinton County, Iowa, and Brookings County, South Dakota, in 1997 and 1998. The managed area of each site was 41.4 km^2. The total area was subdivided into 16 equal-sized (≈260 ha) square blocks arranged in a 4 by 4 grid pattern. Four centermost blocks made up the inner core of the managed area of each site. Adult corn rootworm beetle activity was monitored daily by using Pherocon AM traps (Trécé, Inc., Adair, OK), and was used to determine timing of pretreatment nontarget assessments and treatment applications. Pretreatment sampling, conducted during silking (R1) stage of physiological development (Ritchie et al. 1996), was initiated when rootworm beetle counts indicated adulticide applications were imminent within 10 d, and all pretreatment assessments were completed 24–48 h before bait was applied.

Slam (Micro Flo Company, Memphis, TN), a semiochemical-based insecticidal bait containing 87% cucurbitacin and 13% carbaryl, was aerially applied to corn in the managed area at 561-g product (69.9 g of carbaryl active ingredient) per hectare to control adult *D. virgifera virgifera* and *D. barberi* Smith & Lawrence. Applications were made when beetle counts on traps exceeded a predetermined action threshold of six beetles per trap per day with 10% of females gravid. Slam application timing ranged from 27 July to 6 August among years and sites. Four bait-treated continuous (nonrotated) cornfields were assigned randomly within the managed area of each site to assess impacts of the semiochemical-based insecticide on abundance of major nontarget arthropod groups in eastern Iowa and eastern South Dakota corn field habitats. Four corresponding nonbaited controls of about the same size were selected from nearby (i.e., within 1.6–6.4 km) continuous corn fields immediately outside the perimeter of the areawide managed zone. Due to the large-scale nature of this project and the inherent requirement to use commercial corn production fields, producers in the control areas applied planting-time soil insecticides to prevent corn rootworm larval injury. Growers used one of the following materials for larval control: tefluthrin (Force 1.5G; Syngenta Crop Protection, Greensboro, NC) applied at 0.112 kg [AI]/ha, terbufos (Counter 15G; BASF Ag Products, Research Triangle Park, NC) at 1.12 kg [AI]/ha, or rarely chlorethoxyfos (Fortress 5G; E. I. DuPont De Nemours & Co., Inc., Wilmington, DE) at 0.28 kg [AI]/ha. Thus, each block in this stratified design consisted of a Slam-treated field and its companion control field that did not receive a bait application. In addition to being continuous corn in proximity to the bait-treated perimeter of the managed area, control fields were chosen based on having similar edaphic characteristics (i.e., soil texture, slope, and organic matter content) to maintain comparable habitats to bait-treated counterpart fields in the managed area. Field size for managed and control plots ranged from 29 to 77 ha, and a 1.9-ha (135 by 140-m) subsection within each field was randomly chosen for insect trapping. All assessments of arthropod abundance were made at a minimum of 30 m from the outside edge of each sampled field to avoid or minimize potential confounding edge effects associated with movement of nontarget arthropods from neighboring habitats. Although somewhat unconventional in design, this layout was dictated by the restriction that control plots could not be placed in adulticide-treated rootworm exclusion zones of the areawide-managed central core.

Three sampling methods (pitfall trap, Pherocon AM trap, and whole-plant visual inspection) were used to monitor beneficial arthropods at pretreatment, 1-, and 4-wk intervals after Slam bait applications. Each method was chosen based on its relative ability to quantify specific faunal groups. Sampling was not intended for determining overall community structure and was thus, not season-long; however, the assessments were used to provide valuable information concerning whether these baits would affect abundance of important nontarget arthropod groups. Identifications of arthropods from pitfall samples and sticky traps were carried out by coauthors T.P.M. and N.D.K., respectively, and voucher specimens were deposited in the Severin-McDaniel Insect Research Collection at South Dakota State University.

Pitfall Sampling. Pitfall traps were used to monitor ground-dwelling arthropods. Traps were wide-mouth, 0.95-liter (17-cm depth, 7.5-cm-diameter opening), glass canning jars (Ball, Alltrista Consumer Products Co., Muncie, IN) filled with ≈400 ml of 70% isopropyl alcohol (Cumberland Swan, Inc., Smyrna, TN) and topped with a 1-cm layer of mineral oil (Cumberland Swan) to prevent evaporation of the alcohol. Four corn rows, spaced a minimum of 15 m apart, were randomly chosen within each field for trap placement. Three pitfall traps were installed per sampled row with 25 m of within-row separation between traps. Thus, a total of 12 traps were installed in each treatment plot. Hand-held golf cup cutters (10.2 cm in diameter) were used to create holes for insertion of jars. Holes were dug to a depth of ≈17 cm to allow positioning of the jar opening at the soil surface when deployed. Soil was packed around the opening of each jar, resulting in a smooth soil surface for ground-dwelling arthropods to travel across and be captured by falling into the trap. Pretreatment traps were left in the field for a 7-d collection period and removed from plots 24–48 h before Slam was applied. Counts from these samples provided baseline abundance estimates of major nontarget arthropod groups present in the fields before bait applications. Postapplication pitfall collections were made by installing freshly prepared jars in the same locations and maintaining them for a 7-d collection period beginning at 1 and 4 wk after Slam applications. Arthropods collected from all 12 jars from each plot were identified to at least family level. Specimens from two randomly selected traps for each sampling date and block were identified to species to estimate the most common insect species present. Araneae collections were not identified beyond the family level.

Pherocon AM Traps. Twelve nonbaited yellow Pherocon AM sticky traps were used to monitor flying insect species in the same general locations (i.e., within ≈5 m) and according to the same schedule (i.e., 7-d collection periods and same retrieval dates) as the pitfall traps. The sticky traps were attached to wooden lath stakes (2.5 by 0.6 by 122 cm) and maintained at ≈1 m above the soil surface during each sampling interval. Each trap was positioned such that its adhesive surface would avoid contact with nearby corn plant leaves. Nontarget insects captured on traps were classified to at least family level, and the dominant taxa were identified to species.

Whole-Plant Inspections. Abundance of canopy-dwelling Araneae was assessed at pretreatment, 1 wk after, and 4 wk after bait applications by carrying out whole-plant visual inspections on 100 randomly selected corn plants per plot. Plants selected for visual inspections were at least 15 m away from the area used for sticky trap and pitfall sampling, and the visual counts were completed within 24–48 h of Pherocon AM and pitfall trap installation for each sampling interval. Each plant was examined individually by first approaching it in a manner so as not to disturb any spiders present. Visual examination was carried out on exterior portions of the plant and was followed by inspection and removal of all aboveground structures (e.g., whorls, leaf axils, shanks, ear tissues, husks, and tassels) to reveal spiders not readily visible on the exposed surfaces. Although not the focus of our investigation, this sampling was used to provide additional information regarding potential differences in treatment impacts on ground- and canopy-associated spiders in areawide-managed cornfields. All visual inspections were carried out in situ and thus, did not permit identification beyond the family level.

Statistical Analysis. Nontarget insects were totaled by species and spiders were totaled by family at pretreatment, 1-wk postapplication, and 4-wk postapplication sampling intervals. All data were analyzed by using the χ^2 goodness-of-fit test (Snedecor and Cochran 1989) to compare observed and expected ratios among treatments. The χ^2 test typically compares observed versus expected values at a 1:1 ratio with the assumption of no differences among treatments. In this study, a 1:1 ratio was used solely for pretreatment comparisons of arthropod abundance in control plots and in those assigned to be treated with Slam bait. In many cases, initial pretreatment nontarget arthropod abundance varied considerably among experimental plots. Continued use of the standard 1:1 expectation ratio for comparisons regarding subsequent sampling periods could have thus proven erroneous. Therefore, pretreatment counts were used to create adjusted expectation ratios for the subsequent postapplication comparisons to alleviate potential confounding effects from interplot variability in arthropod abundance before treatment applications. All statistical comparisons for postapplication assessments in Slam-treated corn and controls were based on χ^2 values calculated from observed versus adjusted expectation ratios.

Results

Semiochemical-based bait applications usually resulted in effective control of corn rootworm beetles in the core area throughout the program (Chandler 2003). However, two fields at the Iowa site during 1997 required an additional management intervention beyond the initial Slam application because beetle counts returned to threshold levels. Both plots received a conventional adulticide material (carbaryl at 1.12 kg [AI]/ha) rather than bait. The applications occurred after our 1-wk postapplication assessments had been completed. Therefore, because the carbaryl could have had a confounding effect on abundance of some nontarget arthropod faunal groups in the 4-wk postapplication sampling surveys, those data were excluded from our analyses. Abundance of Carabidae, Staphylinidae, Formicidae, Chrysopidae, Anthocoridae, Coccinellidae, and Araneae was assessed in bait-treated and control corn plots to determine the potential for Slam effects on these important nontarget arthropod groups.

Carabidae. The carabid complex at the South Dakota areawide management location was predominated by *H. pennsylvanicus*, *Evarthus alternans* Casey, *Pterostichus lucublandus* Say, *P. diplophyrus* Chaudoir,

Table 1. Total carabidae collected from pitfall traps in corn fields before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	1,652	2,363	1:1	125.91	<0.0001
		1 wk post	1,780	1,756	1:1.4	121.92	<0.0001
		4 wk post	3,693	1,928	1:1.4	1,392.75	<0.0001
	1998	Pretreatment	2,551	1,189	1:1	496.00	<0.0001
		1 wk post	5,580	5,207	2.1:1	1,349.37	<0.0001
		4 wk post	8,461	2,683	2.1:1	306.58	<0.0001
Iowa	1997	Pretreatment	3,697	2,308	1:1	321.29	<0.0001
		1 wk post	833	687	1.6:1	29.69	<0.0001
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	2,608	2,197	1:1	35.16	<0.0001
		1 wk post	2,221	4,445	1.2:1	1,180.89	<0.0001
		4 wk post	922	1,185	1.2:1	94.35	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 pitfall traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

and *Brachinus cordicollis* Dejean, with these species making up 57, 13, 8, 7, and 6% of the overall composition, respectively. Dominant Carabidae at the Iowa site included *H. pennsylvanicus*, *Galerita janus* F., *P. lucublandus*, *H. caliginosus* F., and *E. alternans*, and these species comprised 24, 23, 18, 17, and 14%, respectively, of all ground beetles collected during the study.

At the South Dakota site in 1997, more ground-dwelling carabid beetles (χ^2 = 125.91, df = 1, $P <$ 0.0001) were present in control plots during the pretreatment sampling period than in those slated for treatment with bait (Table 1). Nonetheless, comparing the observed ratio of carabids in bait-treated plots to that in control plots with the expectation ratio of 1:1.4 indicated that carabid abundance, although relatively constant from pretreatment through 1 wk after bait treatment, was proportionally lower in controls than Slam plots during the 1- (χ^2 = 121.92, df = 1, $P <$ 0.0001) and 4-wk (χ^2 = 1,392.75, df = 1, $P <$ 0.0001) postapplication sampling periods at the South Dakota site in 1997. Initial pretreatment sampling in 1998 indicated that significantly (χ^2 = 496.00, df = 1, $P <$ 0.0001) more (2:1 ratio) carabid beetles were in the plots assigned to receive bait applications than in those that would serve as controls. Although carabid numbers in control plots had increased by a greater extent (χ^2 = 1,349.37, df = 1, $P <$ 0.0001) than those in bait-treated corn during the 1-wk postapplication sampling period, beetle abundance in bait-treated plots rebounded to proportionally even higher levels (χ^2 = 306.58, df = 1, $P <$ 0.0001) than in control plots by 4 wk after treatment applications.

Results from Iowa did not correspond with those from South Dakota. Initial pretreatment captures of carabid beetles in pitfall traps were higher (χ^2 = 321.29, df = 1, $P <$ 0.0001) in bait plots than control plots in 1997 (Table 1). At 1-wk postapplication, the observed ratio (1.2:1) of carabid beetle captures between bait-treated and control plots was significantly divergent (χ^2 = 29.69, df = 1, $P <$ 0.0001) from the expectation ratio of 1.6:1 in that numbers of beetles captured in control plots had increased proportionally more than those in bait plots; however, the disparity among treatments may not have been biologically important because carabid activity had diminished considerably (by 77.5 and 70.2% for the bait and control plots, respectively) by the time 1-wk postapplication pitfall samples were collected.

Total numbers of carabid beetles captured during pretreatment at the Iowa site in 1998 were similar among treatments, and a 1.2:1 expectation ratio was generated. The observed ratio of carabids captured in bait-treated corn to the controls indicated that ground beetles were negatively impacted by the bait at 1 (χ^2 = 1,180.89, df = 1, $P <$ 0.0001) and 4 (χ^2 = 94.35, df = 1, $P <$ 0.0001) wk postapplication (Table 1).

Staphylinidae. The most prominent species of Staphylinidae captured during background sampling in South Dakota were *Platystethus americanus* Erichson and *Bledius coulteri* Hatch at 57.6 and 14.8% of the total captured, respectively. Several other *Bledius* spp. made up the remaining 27.6% of staphylinids caught in pitfall traps in South Dakota. Nearly all (>95%) of the Staphylinidae collected from background samples in Iowa were *P. americanus*.

At the South Dakota site in 1997, comparable numbers (χ^2 = 0.02, df = 1, P = 0.8937) of staphylinid beetles were captured in bait-treated plots and controls during pretreatment pitfall sampling and, accordingly, the expectation ratio was 1:1 (Table 2). Interestingly, a massive shift occurred after treatment applications, with proportionally more (χ^2 = 260.60, df = 1, $P <$ 0.0001) rove beetles collected from bait-treated plots than from controls at 1-wk postapplication in relation to the expectation ratio. The propor-

Table 2. Total Staphylinidae collected from pitfall traps in corn fields before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	113	111	1:1	0.02	0.8937
		1 wk post	291	9	1:1	260.60	<0.0001
		4 wk post	2,275	62	1:1	2,060.45	<0.0001
	1998	Pretreatment	429	117	1:1	178.29	<0.0001
		1 wk post	253	159	3.7:1	72.40	<0.0001
		4 wk post	173	11	3.7:1	26.02	<0.0001
Iowa	1997	Pretreatment	438	284	1:1	32.85	<0.0001
		1 wk post	109	57	1.5:1	1.71	0.1905
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	1,913	3,207	1:1	327.04	<0.0001
		1 wk post	983	573	1:1.7	441.52	<0.0001
		4 wk post	631	307	1:1.7	357.48	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).

[a] Seven-day sampling period with 48 pitfall traps per treatment.

[b] Granular soil insecticides were applied to all plots at planting time.

[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.

[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

tion of staphylinids collected at 4-wk postapplication was even more askew (χ^2 = 2,060.45, df = 1, $P <$ 0.0001) compared with the pretreatment ratio due to a larger increase in staphylinid abundance in bait-treated plots relative to the controls. In 1998, significantly (χ^2 = 178.29, df = 1, $P <$ 0.0001) more rove beetles were present at pretreatment in plots to which bait would be applied than were in the controls. Staphylinid numbers in bait-treated plots dropped by 41% at 1-wk postapplication, whereas abundance in the controls increased. Those opposite trends in rove beetle numbers resulted in a significant (χ^2 = 72.40, df = 1, $P <$ 0.0001) change in the observed ratio compared with the expectation ratio based on pretreatment counts. Although numbers of captured staphylinid beetles in bait-treated plots had declined further by 4 wk postapplication, reductions were more pronounced in the control plots and resulted in a significant (χ^2 = 72.40, df = 1, $P <$ 0.0001) departure from the expectation ratio of 3.7:1.

At the Iowa site in 1997, pretreatment sampling indicated that plots assigned to receive bait applications had more staphylinid beetles (χ^2 = 32.85, df = 1, $P <$ 0.0001) than the control plots (Table 2). The disparity resulted in an expectation ratio of 1.5:1 for bait-treated to control plots, and the observed ratio among these treatments at 1-wk postapplication did not significantly deviate from the expected (χ^2 = 1.71, df = 1, P = 0.1905). Initial abundance of Staphylinidae was inconsistent among treatment plots at the Iowa location in 1998, with more (χ^2 = 327.04, df = 1, $P <$ 0.0001) captured in plots selected for controls than in those that would receive bait applications. Although the difference suggested an expectation ratio of 1:1.7 for bait to nonbait plots, the observed ratio was inverted with proportionally more staphylinids captured in bait-treated plots than in controls at 1 (χ^2 = 441.52, df = 1, $P <$ 0.0001) and 4 (χ^2 = 357.48, df = 1, $P <$ 0.0001) wk postapplication.

Formicidae. The species *Lasius neoniger* Emery, *Lasius umbratus* (Nylander), and *Myrmica americana* Weber made up 43, 21, and 9%, respectively, of the ants captured in pitfall traps at the South Dakota study site. Similarly, *L. neoniger*, *L. umbratus*, *M. americana*, and *Formica limata* Wheeler accounted for 43, 22, 15, and 9%, respectively, of formicids recovered from pitfall traps at the Iowa location.

Comparable numbers (χ^2 = 1.05, df = 1, P = 0.3051) of ants were present among plots before treatments were applied at the South Dakota location in 1997; however, observed ratios differed from the expectation ratio at both 1 (χ^2 = 6.14, df = 1, P = 0.0132) and 4 (χ^2 = 101.17, df = 1, $P <$ 0.0001) wk postapplication, with proportionally more ants captured in bait-treated plots than controls (Table 3). Similar results were observed at the South Dakota site in 1998. Pretreatment samples indicated a preponderance (χ^2 = 101.17, df = 1, $P <$ 0.0001) of ants in plots that would be used as controls. Pitfall trapping at 1 wk postapplication indicated that ant abundance in bait-treated plots and controls remained at proportionally similar (χ^2 = 0.15, df = 1, P = 0.7011) levels to the expectation ratio of 1:4. At 4 wk postapplication, however, the observed ratio was significantly (χ^2 = 157.93, df = 1, $P <$ 0.0001) more slanted toward increased numbers of ants captured in bait-treated plots than controls.

At the Iowa site in 1997, more ants (χ^2 = 119.16, df = 1, $P <$ 0.0001) were initially present in plots assigned to receive bait treatment than the no-bait controls (Table 3). The observed ratio of ants in bait-treated plots to controls indicated that abundance in the two treatments remained at similar proportions (χ^2 = 2.96, df = 1, P = 0.0852) at 1 wk after treatment applications. Similar to 1997, ants also were more abundant (χ^2 = 208.93, df = 1, $P <$ 0.0001) in plots planned for bait applications than in controls before bait applications at the Iowa site in 1998; however, proportionally fewer ants were captured in bait-treated plots than controls

Table 3. Total Formicidae collected from pitfall traps in corn fields before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	34	43	1:1	1.05	0.3051
		1 wk post	71	58	1:1.3	6.14	0.0132
		4 wk post	139	29	1:1.3	101.17	<0.0001
	1998	Pretreatment	52	210	1:1	95.28	<0.0001
		1 wk post	24	89	1:4	0.15	0.7011
		4 wk post	63	22	1:4	157.93	<0.0001
Iowa	1997	Pretreatment	216	41	1:1	119.16	<0.0001
		1 wk post	146	38	5.3:1	2.96	0.0852
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	731	273	1:1	208.93	<0.0001
		1 wk post	142	158	2.7:1	98.26	<0.0001
		4 wk post	165	82	2.7:1	4.49	0.0341

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 pitfall traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

during both 1-wk ($\chi^2 = 98.26$, df = 1, $P < 0.0001$) and 4-wk ($\chi^2 = 4.49$, df = 1, $P = 0.0341$) postapplication sampling periods compared with the expectation ratio.

Chrysopidae. Dominant Chrysopidae recovered from sticky traps belonged to the *Chrysoperla* complex. Lacewings in this genus have a broad habitat range (Brooks and Barnard 1990). The most common and widespread species inhabiting North American cereal crops is thought to be *Chrysoperla plorabunda* (F.) (Brewer and Elliott 2004). Species determinations for green lacewings were not possible in our study because chrysopids belonging to this complex are most appropriately distinguished by internal features of their genitalia and also by unique phenotypical characteristics of their calling song (Henry et al. 1993).

Sticky trap results on the green lacewings were variable and thus, somewhat inconclusive. The observed ratio of green lacewings in bait-treated to control plots at the South Dakota location in 1997 underwent a significant shift to more in the controls at both 1 ($\chi^2 = 60.00$, df = 1, $P < 0.0001$) and 4 ($\chi^2 = 10.05$, df = 1, $P = 0.0015$) wk postapplication (Table 4); however, those findings were not repeated in 1998. At the Iowa site, observed ratios of chrysopids captured in bait-treated corn and control plots at 1 wk postapplication of bait did not deviate significantly ($\chi^2 \leq 1.14$, df = 1, $P \geq 0.2850$) from the expected ratio in

Table 4. Total Chrysopidae collected on Pherocon AM sticky traps in corn before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	52	11	1:1	26.68	<0.0001
		1 wk post	47	44	4.7:1	60.00	<0.0001
		4 wk post	130	47	4.7:1	10.05	0.0015
	1998	Pretreatment	32	23	1:1	1.47	0.2249
		1 wk post	9	5	1.4:1	0.21	0.6443
		4 wk post	31	33	1.4:1	2.51	0.1133
Iowa	1997	Pretreatment	36	10	1:1	14.70	0.0001
		1 wk post	79	25	3.6:1	0.34	0.5629
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	1	1	1:1	0.00	1.0000
		1 wk post	9	5	1:1	1.14	0.2850
		4 wk post	23	1	1:1	20.17	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 Pherocon AM traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

Table 5. Total Anthocoridae collected on Pherocon AM sticky traps in corn before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	10	21	1:1	3.90	0.0482
		1 wk post	0	21	1:2.1	10.02	0.0016
		4 wk post	172	113	1:2.1	18.48	<0.0001
	1998	Pretreatment	7	20	1:1	6.26	0.0124
		1 wk post	18	29	1:2.8	3.76	0.0524
		4 wk post	46	85	1:2.8	5.80	0.0161
Iowa	1997	Pretreatment	114	104	1:1	0.46	0.4982
		1 wk post	447	624	1.1:1	487.90	<0.0001
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	0	0	NE[e]	NE	NE
		1 wk post	1,931	1,704	1:1	14.18	0.0002
		4 wk post	727	588	1:1	14.69	0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 Pherocon AM traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.
[e] Nonestimable using χ^2 statistic.

1997 or 1998, whereas green lacewings had become proportionally more abundant ($\chi^2 = 20.17$, df = 1, $P < 0.0001$) in bait plots than in controls at 4 wk postapplication in the second year of the experiment.

Anthocoridae. The minute pirate bug, *Orius tristicolor* White, was the most common anthocorid captured on sticky traps throughout the study at both locations. At the South Dakota site in 1997, the observed ratio of anthocorids captured in bait-treated versus control plots was significantly ($\chi^2 = 10.02$, df = 1, $P = 0.0016$) slanted toward more in the controls during the 1-wk postapplication trapping interval (Table 5). The observed ratio became inverted and a significant ($\chi^2 = 18.48$, df = 1, $P < 0.0001$) shift to proportionally more insects present in bait-treated plots was observed during the 4-wk postapplication sampling period that year. Similarly, in 1998, the observed ratio during the 4-wk postapplication assessment was also a significant ($\chi^2 = 5.80$, df = 1, $P = 0.0161$) change from the expectation ratio due to a proportionally greater increase in Anthocoridae captured in bait-treated corn than in the controls.

Sticky trap captures at 1 wk postapplication at Iowa in 1997 indicated a reduction ($\chi^2 = 487.90$, df = 1, $P < 0.0001$) in the proportion of Anthocoridae caught in bait-treated corn versus the controls (Table 5). Contrarily, the observed ratios in both postapplication sampling periods in 1998 had shifted due to greater proportional increases ($\chi^2 \geq 14.18$, df = 1, $P \leq 0.0002$) of anthocorids caught in bait-treated plots.

Coccinellidae. Dominant Coccinellidae captured on sticky traps at the South Dakota areawide management site were *Adalia bipunctata* (L.) and *Hippodamia parenthesis* Say, at 60.5 and 34.6% of the overall species composition, respectively. The species *Cycloneda munda* Say and *Coleomegilla maculata* De Geer were most prominent among Coccinellidae captured in background sampling at the Iowa site and made up 55.9 and 43.2% of the species composition, respectively.

At the South Dakota site in 1997, captures of coccinellid beetles on Pherocon AM traps before treatment applications were similar ($\chi^2 = 0.00$, df = 1, $P = 1.0000$) among plots that would later receive bait and those that would serve as controls (Table 6). Trapping results at 1 wk postapplication indicated a major increase in Coccinellidae in control plots and a concurrent decrease in bait-treated corn. This disparity resulted in a significant ($\chi^2 = 146.88$, df = 1, $P < 0.0001$) departure from the expectation ratio of 1:1. Sticky trap data from both 1- and 4-wk postapplication sampling efforts for all other site–year combinations indicated that the Coccinellidae had either increased ($\chi^2 \geq 5.73$, df = 1, $P \leq 0.0167$) after bait applications or were not significantly impacted ($\chi^2 = 0.04$, df = 1, $P = 0.8483$) when observed ratios were compared with corresponding pretreatment ratios.

Araneae. *Pitfall Trapping.* Background samples (pitfall traps at pretreatment combined with those from control plots throughout the experiment) indicated that the Lycosidae, Salticidae, Clubionidae, Pholcidae, and Amaurobiidae represented 26, 18, 16, 16 and 8%, respectively, of the overall familial composition of spiders at the South Dakota location. Similarly, the Pholcidae, Lycosidae, Amaurobiidae, and Salticidae made up 32, 29, 8, and 7% of spiders captured in pitfall traps in Iowa. The family Gnaphosidae also was somewhat abundant in Iowa at 9% of all spiders captured in background samples.

Pretreatment pitfall sampling in South Dakota in 1997 indicated that spider abundance in plots assigned for bait treatment and the controls was initially at a 1:1 ratio (Table 7). Spiders were considerably more abundant in both treatments during the 1-wk postapplica-

Table 6. Total Coccinellidae collected on Pherocon AM sticky traps in corn before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	56	56	1:1	0.00	1.0000
		1 wk post	39	321	1:1	146.88	<0.0001
		4 wk post	84	111	1:1	0.04	0.8483
	1998	Pretreatment	18	101	1:1	888.90	<0.0001
		1 wk post	39	120	1:5.6	11.02	0.0009
		4 wk post	35	125	1:5.6	5.73	0.0167
Iowa	1997	Pretreatment	23	70	1:1	23.75	<0.0001
		1 wk post	213	196	1:3	164.83	<0.0001
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	4	13	1:1	4.77	0.0291
		1 wk post	332	251	1:3.2	362.78	<0.0001
		4 wk post	48	55	1:3.2	30.58	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 Pherocon AM traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

tion sampling period, although the observed ratio indicated a greater rate of increase ($\chi^2 = 47.31$, df = 1, $P < 0.0001$) for spiders in control plots than in bait-treated corn. Similarly, the observed ratio at 4 wk postapplication was significantly ($\chi^2 = 127.24$, df = 1, $P < 0.0001$) different from the expectation ratio of 1:1 and demonstrated that although ground-dwelling spiders remained at relatively constant levels in the bait-treated plots from 1 to 4 wk postapplication, they were increasingly more abundant in the controls. Pretreatment captures of Araneae in South Dakota in 1998 resulted in an expectation ratio of 1.3:1 spiders in bait and control plots, respectively. Although the observed ratio for the 1-wk postapplication sampling period underwent a significant ($\chi^2 = 21.23$, df = 1, $P < 0.0001$) change in favor of spider numbers in the controls, densities in both bait-treated and control plots had increased to nearly three-fold of that in the pretreatment sampling period. Thus, the difference between the expectation ratio (1.3:1) and observed ratio (1.1:1) for 1-wk postapplication pitfall samples may not have been of practical significance. A major drop in abundance of ground-dwelling spiders occurred in bait plots at the 4-wk postapplication pitfall sampling period, and the resulting observed ratio between bait and control plots was significantly different ($\chi^2 = 510.50$, df = 1, $P < 0.0001$) from the expected ratio.

At the Iowa site in 1997, significantly ($\chi^2 = 243.81$, df = 1, $P < 0.0001$) more spiders were recovered during the pretreatment sampling period from pitfall

Table 7. Total Araneae collected from pitfall traps in cornfields before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	525	513	1:1	0.14	0.7096
		1 wk post	1,179	1,503	1:1	47.31	<0.0001
		4 wk post	1,151	1,721	1:1	127.24	<0.0001
	1998	Pretreatment	483	375	1:1	13.59	0.0002
		1 wk post	1,270	1,187	1.3:1	21.23	<0.0001
		4 wk post	519	1,237	1.3:1	510.50	<0.0001
Iowa	1997	Pretreatment	601	168	1:1	243.81	<0.0001
		1 wk post	524	99	3.6:1	12.76	0.0004
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	224	113	1:1	36.56	<0.0001
		1 wk post	818	409	2:1	0.02	0.9016
		4 wk post	506	104	2:1	74.10	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Seven-day sampling period with 48 pitfall traps per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

Table 8. Total Araneae observed in whole-plant visual sampling of corn before and after treatment with a semiochemical-based bait adulticide, Brookings County, South Dakota, and Clinton County, Iowa, 1997–1998

State	Yr	Sampling period[a]	Total Carabidae		Expectation ratio[c]	χ^2	P
			Bait[b]	Control[b]			
South Dakota	1997	Pretreatment	17	31	1:1	4.08	0.0433
		1 wk post	19	31	1:1.8	0.15	0.7006
		4 wk post	32	36	1:1.8	4.04	0.0444
	1998	Pretreatment	8	22	1:1	6.53	0.0106
		1 wk post	4	105	1:2.8	29.54	<0.0001
		4 wk post	29	27	1:2.8	18.01	<0.0001
Iowa	1997	Pretreatment	29	27	1:1	0.07	0.7893
		1 wk post	33	59	1:1	9.35	0.0022
		4 wk post[d]	—	—	—	—	—
	1998	Pretreatment	20	45	1:1	9.62	0.0019
		1 wk post	45	36	1:2.2	23.29	<0.0001
		4 wk post	46	34	1:2.2	26.76	<0.0001

Probability of a significant difference between totals within row by using χ^2 goodness-of-fit test (Snedecor and Cochran 1989).
[a] Four hundred whole-plant inspections per treatment.
[b] Granular soil insecticides were applied to all plots at planting time.
[c] Pretreatment expectation ratio was 1:1; however, expectation ratios at 1 and 4 wk postapplication were adjusted based on observed ratios from pretreatment sampling.
[d] Data not presented because a potentially confounding application of a conventional adulticide (carbaryl at 1.12 kg [AI]/ha) was made at the request of cooperating grower due to excessive corn rootworm beetle infestations.

samples in plots assigned to receive bait (Table 7). The observed ratio became even more disparate (χ^2 = 12.76, df = 1, P = 0.0004) than the expected ratio (3.6:1) by the time the 1-wk postapplication assessments were made with over five-fold more spiders present in bait-treated plots than the controls. In 1998, pretreatment sampling in Iowa indicated that more (χ^2 = 36.56, df = 1, $P < 0.0001$) spiders were initially present in plots assigned to receive bait than those planned to serve as controls, and the ratio remained nearly identical at ≈2:1 through the 1-wk postapplication sampling period. Interestingly, although counts at 4 wk postapplication indicated spider densities had decreased in both bait-treated and control plots, the reduction was considerably more pronounced in the controls and resulted in a major deviation (χ^2 = 36.56, df = 1, $P < 0.0001$) from the initial expectation ratio.

Whole-Plant Inspections. Assessments of spider abundance via whole-plant inspections indicated that canopy-associated spiders were initially more numerous (χ^2 = 4.08, df = 1, P = 0.0433) in plots that would serve as controls and, unlike the ground-dwelling Araneae captured in pitfall traps, the observed ratio (bait-treated to controls) of spider abundance in the corn plant canopy at 1 wk postapplication did not differ significantly (χ^2 = 0.15, df = 1, P = 0.7006) from the expectation ratio (1:1.8) in South Dakota in 1997 (Table 8). The observed ratio at 4 wk postapplication was, however, different from the expected in that canopy-dwelling spiders were proportionally more abundant (χ^2 = 4.04, df = 1, P = 0.0444) in bait-treated plots than in the controls. Results from the South Dakota site in 1998 were similar to 1997. Although spider counts at 1 wk postapplication had increased from pretreatment levels by a greater margin (χ^2 = 29.54, df = 1, $P <$ 0.0001) in control plots than in bait-treated corn habitats, the observed ratio at the 4-wk postapplication assessment demonstrated that canopy-dwelling Araneae became proportionally more numerous (χ^2 = 18.01, df = 1, $P < 0.0001$) in bait-treated corn than in controls when compared with the expectation ratio of 1:2.8.

Pretreatment whole-plant inspections at Iowa in 1997 indicated that spiders were somewhat evenly distributed (χ^2 = 0.07, df = 1, P = 0.7893) among plots assigned to receive bait and those that would serve as controls (Table 8). Spiders became proportionally less abundant (χ^2 = 9.35, df = 1, P = 0.0022) in bait-treated corn than in controls compared with the expected 1:1 ratio at 1 wk postapplication. Pretreatment counts at the Iowa site in 1998 indicated that more (χ^2 = 9.62, df = 1, P = 0.0019) spiders were initially present in the controls, and resulted in an expectation ratio of 1:2.2; however, canopy-dwelling Araneae became proportionally more abundant (χ^2 = 23.29, df = 1, $P < 0.0001$) in bait-treated corn at the 1-wk postapplication assessment and remained proportionally more numerous in bait plots at 4 wk postapplication (χ^2 = 26.76, df = 1, $P < 0.0001$).

Discussion

Previous investigators have observed major (>90%) decreases in corn rootworm infestations and reduced levels of root feeding injury as a result of semiochemical-based adulticidal bait applications (Lance and Sutter 1992), especially when used in areawide suppression programs (Lingren 1999, Chandler 2003). These birational formulations also offer important benefits with regard to environmental stewardship in corn rootworm management systems. First, baits involve only a small fraction of the active ingredient used per unit area in conventional insecticide applications. Second, cucurbitacin-based baits are somewhat selective to the target pest group, diabroticite beetles, because they act dually as strong arrestants and feeding stimulants (Metcalf et al. 1982) to this important complex of corn pests. This study was undertaken to assess the impacts of semiochemical-based bait applications on several nontarget arthropod groups common to corn field habitats in eastern South Dakota and eastern Iowa.

Impacts of the semiochemical-based bait were variable and often not detectable for several of the arthropod groups monitored. No lasting deleterious effects from the bait were observed on staphylinid abundance in areawide-managed landscapes. Indeed, rove beetle numbers usually increased after corn was treated with the bait. This could possibly have been due to sublethal levels of the bait rendering corn rootworm beetles more prone to capture by predatory staphylinids. Results on Carabidae were divergent among the two study sites. For example, 4-wk post-application samples in South Dakota consistently showed increases in carabid beetle abundance in bait-treated plots in both study years, whereas carabids declined after bait applications at Iowa in the second year of the experiment. Any of a variety of biotic and abiotic factors could have influenced the conflicting results observed on Carabidae at Iowa. Our data do not suggest a definite impact, either negative or positive, of the bait applications on abundance of this group. Previous research suggests that bait applications in our study were probably not responsible for the observed declines in carabid abundance at the Iowa site. Ellsbury et al. (1996b) fed *D. v. virgifera* Slam-killed beetles directly to adults of five carabid species belonging to *Harpalus* and *Pterostichus*, two of the predominant ground beetle genera at both study sites in our experiment, and observed zero mortality. Similarly, McKenzie et al. (2002b) observed a general lack of negative impacts by the bait in similar consumption assays on adult *H. pennsylvanicus*, also an abundant species in both of our study sites. If semiochemical-based rootworm baits containing carbaryl insecticide pose any genuine risk to Carabidae in eastern Iowa cornfields, it should be noted that conventional soil-applied insecticides have been shown to impose significant harmful effects on this beneficial group of nontargets. For example, Reed et al. (1992) evaluated the contact and volatile toxicity of organophosphate soil insecticides common to corn production in North America, and determined that the more volatile compounds in the study contributed to reductions in carabid populations. Therefore, management of rootworm populations by using the areawide approach with semiochemical-based insecticides may still be environmentally superior to the use of soil insecticides in relation to conservation of this important group of beneficials.

Results on Formicidae also varied among the two study sites. Greater numbers of ants were collected from pitfall traps in bait-treated plots than in conventionally protected corn in South Dakota, whereas ant abundance was proportionally reduced in bait-treated plots in Iowa. Species composition also could have influenced these results, although to a much lesser degree. Nine percent of the ants captured at the Iowa location were *F. limata*, whereas that species was not detected in the South Dakota samples. Additionally, *M. americana* was 6% more abundant in the overall species composition at the Iowa site than in South Dakota.

Consistent patterns were lacking for bait impacts on Chrysopidae. Negative effects of the semiochemical-based adulticide were restricted to one site during the first year of the study. The relative absence of deleterious effects on lacewing populations in our study is supported by the findings of Ellsbury et al. (1996a) who observed no negative impacts on survival of green lacewing, *C. carnea*, larvae presented with semiochemical-based insecticidal baits on treated corn leaves in enclosed chambers. The likelihood of such bait formulations affecting adult Chrysopidae is also especially small because these insects are only predacious as larvae (Brewer and Elliott 2004).

Canopy-associated spiders escaped harm in our study and, moreover, seemed to frequently benefit from the bait applications. This was observed most often at 4 wk after application of the semiochemical-based insecticide. These findings supported the results of Hoffmann et al. (2000) who, at 14 d after treatment, observed no major negative impacts from areawide-applied Slam on spiders common to Texas corn field canopies. Results of McKenzie et al. (2002a) also were similar to ours in that canopy-associated Araneae were not negatively affected by Slam in Kansas corn fields for up to 16 d after treatment. In our study, nontarget effects were assessed for up to 4 wk after bait applications. Abundance of ground-dwelling Araneae was reduced more often than canopy-associated Araneae and most other faunal groups; however, this finding should be interpreted with caution because ground-dwelling spiders were recovered at very low numbers throughout the investigation. One or more of the following could have contributed to our observed differences in bait impacts between canopy- and ground-associated Araneae: 1) prey species encountered by spiders in the corn canopy were impaired and more prone to capture by canopy-dwelling spiders due to sublethal levels of carbaryl, thus allowing greater spider survival in bait-treated habitats; 2) the live prey captured by Araneae in the canopy lacked carbaryl residues; 3) spiders scavenging on the ground were secondarily intoxicated by consuming more bait-killed beetles than those capturing live prey in the canopy; or similarly, 4) bait-killed corn rootworm beetle cadavers consumed by ground-dwelling spiders contained higher carbaryl concentrations than sublethally or nonexposed beetles consumed by canopy-dwelling spiders. Further study would be needed to more fully understand these interactions.

Abundance of some nontarget groups (e.g., Anthocoridae, Coccinellidae, Staphylinidae, Anthocoridae, and canopy-dwelling Araneae) in our study was often proportionally greater in bait-treated corn than in conventionally protected fields in relation to pretreatment-based expectation ratios. Most other groups showed no consistent patterns, either positive or negative, in relation to the bait applications. Abundance of many of the nontarget faunal groups seemed to be governed more predominantly by other biotic and abiotic mortality factors than by the bait applications. Overall, these findings suggest that areawide applications of semiochemical-based baits containing substantially reduced concentrations of toxicant active ingredient for rootworm management in corn are not likely to be deleterious to most of the nontarget faunal groups we surveyed, especially in comparison with conventional soil insecticides. The general lack of consistent negative impacts on these groups of beneficials is a major positive outcome from this research. These results should be interpreted carefully due to restrictions associated with the required placement of control plots outside the bait-treated core of each areawide management site.

It also should be noted that although the Slam bait product used in our nontarget research is no longer produced by the Micro Flo Company, other similar semiochemical-based baits (e.g., Cide-Trak or Invite) remain available and are designed for use with carbaryl or other insecticidal compounds at low active ingredient rates per hectare. These alternative adulticidal baits seem to pose little risk to a diverse range of nontarget arthropod groups and could potentially allow for major reductions in insecticide active ingredient needed per hectare compared with conventional at-plant insecticide treatments. Therefore, semiochemical-based insecticide baits should be considered as biorational alternatives to prophylactic use of soil insecticides for rootworm management in North American corn production systems.

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